SOME GEOLOGIC CONCLUSIONS FROM GEODETIC DATA

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Communicated by A. O. Leuschner. Read before the Academy, November 16, 1920

For a number of years geodetic data were collected for the purpose of controlling surveys and maps and for the determination of the shape and size of the earth. But in recent years they are also extensively used in investigations dealing with geological and geophysical problems. These investigations have included data for the United States, India, Canada and a small part of Europe.

The investigations in isostasy have proved that for the areas considered there is approximately the same mass in each column of unit cross-section extending from the surface of the earth down to a depth of, say, 75 miles. This statement is justified regardless of what the depth of compensation actually is, for the deficiency or excess of mass in a few miles at the depth of approximately 75 miles is a small percentage of the mass of the whole column. With regard to depth of compensation it may safely be said that there is no sharply defined surface which is at uniform depth below sea level, limiting the isostatic compensation. It is probable that there is a zone, rather than a surface, which limits the compensation.

We have no evidence as to the manner in which the compensation is distributed vertically, but the uniform distribution, which was adopted in order to make the computations more feasible, is as logical as any other simple method. Regardless of what the method of distribution is actually, the conclusions reached from the isostatic researches cannot be seriously affected.

What is the area of the cross-section of the unit column that may be in equilibrium is a matter which is in doubt, but as data are accumulated the area of the cross-section is successively lessened.

It has been found that large areas are in almost perfect isostatic balance and it seems to be very probable that an area of about 70 miles square is very closely compensated. This is the area of one square degree at the equator, or very nearly so.

It has been found that the distribution of the compensation of a topographic feature horizontally to a distance of about 60 kilometers from the feature gives as consistent results as local compensation, but when the compensation is distributed horizontally to a distance of 170 kilometers the results are not so accordant as with local distribution of the compensation.[1]

It must be held that any system for correcting geodetic data for the effect of topography and isostatic compensation, which makes the computed values of gravity agree closely with the observed values in different

Effect of Gravity Anomalies of the Compensation for Inner Zones

Number and name of station	Elevation H	Isostatic anomaly in dynes	Cor. to discard comp. out to and including		Anomalies with isostatic comp. omitted to	
			Zone L. (17.9 mi.) In dynes	Zone M. (36.5 mi.) In dynes	Zone L. In dynes	Zone M. In dynes
	Meters					
41 Wallace, Kans.	1005	−0.012	−0.027	−0.048	−0.039	−0.060
42 Colorado Springs, Colo.	1841	−0.007	−0.054	−0.094	−0.061	−0.101
43 Pikes Peak, Colo.	4293	+0.021	−0.070	−0.113	−0.049	−0.092
44 Denver, Colo.	1638	−0.016	−0.038	−0.076	−0.054	−0.092
45 Gunnison, Colo.	2340	+0.020	−0.063	−0.120	−0.043	−0.100
46 Grand Junc., Colo.	1398	+0.024	−0.041	−0.082	−0.017	−0.058
47 Green River, Utah	1243	−0.021	−0.033	−0.067	−0.054	−0.058
48 Pleasant Val. Junc., Utah	2191	+0.004	−0.060	−0.103	−0.056	−0.099
49 Salt Lake City, Utah	1322	+0.010	−0.040	−0.075	−0.030	−0.065
50 Grand Canyon, Wyo.	2386	−0.002	−0.061	−0.108	−0.063	−0.110
51 Norris Geyser Basin, Wyo.	2276	+0.021	−0.059	−0.104	−0.038	−0.083
52 Lower Geyser Basin, Wyo.	2200	−0.001	−0.058	−0.103	−0.059	−0.104
55 Mt. Hamilton, Cal.	1282	−0.003	−0.014	−0.017	−0.017	−0.020
63 El Paso, Tex.	1146	+0.007	−0.030	−0.054	−0.023	−0.047
64 Nogales, Ariz.	1181	−0.050	−0.029	−0.046	−0.079	−0.096
67 Goldfield, Nev.	1716	−0.013	−0.043	−0.074	−0.056	−0.087
68 Yavapai, Ariz.	2179	+0.001	−0.045	−0.080	−0.044	−0.079
70 Gallup, N. Mex.	1990	−0.013	−0.053	−0.095	−0.066	−0.108
71 Las Vegas, N. Mex.	1960	+0.003	−0.053	−0.094	−0.050	−0.091
75 Lead, S. Dak.	1590	+0.052	−0.038	−0.064	+0.014	−0.012
81 Sisson, Cal.	1048	−0.010	−0.033	−0.058	−0.043	−0.068
82 Rock Springs, Wyo.	1910	+0.013	−0.052	−0.093	−0.039	−0.080
98 Alpine, Tex.	1359	+0.021	−0.034	−0.061	−0.013	−0.040
99 Farwell, Tex.	1259	−0.016	−0.030	−0.055	−0.046	−0.071
102 Cloudland, Tenn.	1890	+0.004	−0.025	−0.039	−0.021	−0.035
109 Sheridan, Wyo.	1150	+0.032	−0.032	−0.068	0.000	−0.036
110 Boulder, Mont.	1493	−0.015	−0.046	−0.077	−0.061	−0.092
114 Truckee, Cal.	1805	−0.028	−0.051	−0.085	−0.079	−0.113
115 Winnemucca, Nev.	1311	−0.009	−0.032	−0.062	−0.041	−0.071
116 Ely, Nev.	1962	−0.021	−0.055	−0.094	−0.076	−0.115
117 Guernsey, Wyo.	1322	+0.036	−0.031	−0.062	+0.005	−0.026
195 Lander, Wyo.	1635	+0.019	−0.047	−0.090	−0.028	−0.071
198 Edgemont, S. Dak.	1066	+0.054	−0.028	−0.052	+0.026	+0.002
202 Moorecroft, Wyo.	1295	+0.021	−0.031	−0.058	−0.010	−0.037
269 Hill City, S. Dak.	1518	+0.042	−0.040	−0.067	+0.002	−0.025
270 Newcastle, Wyo.	1328	+0.029	−0.035	−0.064	−0.006	−0.035
271 Bridgeport, Neb.	1114	−0.008	−0.029	−0.053	−0.037	−0.061
272 Buford, Wyo.	2396	+0.046	−0.057	−0.100	−0.011	−0.054
273 Boulder, Colo.	1630	−0.014	−0.048	−0.092	−0.062	−0.106
274 Lafayette, Colo.	1595	−0.020	−0.040	−0.081	−0.060	−0.101
275 Brighton, Colo.	1511	−0.006	−0.038	−0.073	−0.044	−0.079
276 Idaho Springs, Colo.	2303	+0.022	−0.068	−0.120	−0.046	−0.098
Mean with regard to sign		+0.005	0.043	0.077	−0.037	−0.072
Mean without regard to sign		0.019			0.040	0.072

parts of the earth and for various types of topography, is very close to the ideal or true system. While the isostatic investigations have been confined to only a portion of the earth's surface it seems probable that all land areas will be found to be in isostatic equilibrium.

A test was made to show whether the compensation of small areas of topography could be ignored without seriously affecting the results. Forty-two stations having high elevations were selected for the test. The elevations of these stations varied from 3000 to 14,000 feet. When the compensation of the topography for a circle with a radius of 17.9 miles was ignored the gravity anomalies became much larger and 37 of the 42 anomalies had negative signs. When the area of the circle was given a radius of 36.5 miles the anomalies were still further increased and all of the anomalies except one had the negative sign. With the small circle the mean anomaly with regard to sign is -0.037 dyne while with the larger circle the mean anomaly with regard to sign is -0.072 dyne. When it is considered that the mean anomaly with regard to sign for these 42 stations under consideration, all at high elevations, is only $+0.005$ dyne, it is realized that the ignoring of the local compensation is not justified. The table preceding shows these results.

This test shows that, for even very small areas, the topography is at least largely compensated. This is a most important conclusion for by analogy no such mass as the sedimentary material forming the delta of a large river entirely escapes isostatic compensation as has been held by some investigators.[2]

There are very definite relations between the gravity anomalies and the Cenozoic and Pre-Cambrian formations. The Cenozoic stations have negative anomalies in nearly all cases, and the largest anomalies are found at stations located on this formation. The anomalies at the stations on the Pre-Cambrian areas of limited extent are nearly all positive.[3]

The writer made an investigation of these relations and arrived at the conclusion that the negative sign of the Cenozoic anomalies is due in great part to the abnormally light material of that formation. Of course it is necessary to consider the effect of the Cenozoic material which extends below sea level. Nearly all Cenozoic formations are at comparatively small elevations and the abnormal density of the material which may be above sea level could account for only a very small part of the anomalies at Cenozoic stations.

In a similar manner it was found that the existence of abnormally dense material in the Pre-Cambrian formation will account for the positive sign of the anomalies at stations on that formation. It will be necessary, as in the case of the Cenozoic formation, to consider the material that extends below sea level.

These are logical conclusions for it is not conceivable that with a whole country (the United States, for example) in practically perfect isostatic

balance, the column under an area of sedimentation should be too light and that the column under an area subjected to long erosion should be too heavy.

The writer's conclusion has been confirmed by a recent investigation in India.[4]

If the columns under the Cenozoic and the Pre-Cambrian formations are in isostatic equilibrium, then there must exist the compensation not only of the material which is above sea level but of the deficiency of matter in the Cenozoic and the excess of matter in the Pre-Cambrian material which exist below sea level.

It is inconceivable that 20,000 or 30,000 feet of sediment all deposited at a low elevation, approximately sea level, could take the place of an equal volume of material presumably of normal density and still have the column contain normal mass, without there having occurred an increase in density in the material of the column to balance the deficiency of mass in the volume occupied by the recent sedimentary material. If the Cenozoic material is 30,000 feet thick, the deficiency in mass is about 3000 feet, and the isostatic compensation will be equal to this amount. In the 75-mile column the increase in density necessary to balance the Cenozoic deficiency will be about $^3/_4$ of 1%, if we assume that the average density throughout the column is approximately three. If the density is greater than that, the percentage will be proportionately increased.

In order to maintain the isostatic balance a mass equivalent to 27,000 feet of Cenozoic material must have been transferred from the column under the Cenozoic formation.

The contraction of the material in the column under the Cenozoic formation may have begun before sedimentation was initiated, but further contraction and consequent increase in density must have taken place with the sedimentation for, otherwise, the surface of the column would have stood at some times much above sea level, which seems to have been improbable.

The evidence *available from geodetic investigations* indicates in the strongest way that land masses are in equilibrium and that this equilibrium exists in comparatively small areas. A natural inference is that land masses have been equally in equilibrium in former geologic periods.

How, then, can an area of sedimentation at approximately sea level, of one age, be a mountainous area in a succeeding one?

Mountain formation by transportation of material horizontally from one column in equilibrium to another column in equilibrium could not take place without destroying the isostatic balance. Of course, material is transported from one column to another (surface transportation after erosion is not included in this statement) but this is when the columns are out of balance and the movement renews the isostatic equilibrium between the two columns. Mountain masses are not excess loads on the earth, as is proved by the existence of the isostatic conditions in mountainous

regions, therefore the materials forming the mountains were not moved horizontally to the region. We are forced to the conclusion that the mountains must result from vertical movements in the columns under them. The vertical movement evidently must be due to an expansion and consequent decrease in density in the material of the column.

When we consider that all extensive areas of recent sedimentation on which we have gravity stations are in isostatic equilibrium and that mountain systems formed in previous sedimentary areas are also in equilibrium, we have no alternative to the view that an actual expansion of the columns under the mountains has taken place.

The objection will be raised that there is abundant evidence that there have been horizontal movements in the materials forming the mountains. This is granted but is it necessary to go far beyond the mountain area for the forces acting laterally which cause the observed horizontal movements? Can we not conceive that, in the uplifting of the mountains of the Appalachian and Himalayan systems, for instance, the vertically acting forces will cause the material to progress in the directions of least resistance and that these directions may be horizontal in some cases and in others at varying angles with the vertical.

During the period of sedimentation, material probably was not laid down in smooth concentric sheets but in irregular ways. In the process of uplift, due to expansion, the rate of expansion would undoubtedly be different in different parts of the zone. The sediments are of varying thickness, the material on which the sediment had been deposited varies in composition and consequently in its resistance to uplift, and finally there is cubical expansion of the material which must cause the material at the borders, but outside of the columns, to modify somewhat the upward movements of the expanding mass. At least this effect must be exerted near the upper part of the expanding column. The areas affected are not small for the area of the base of the Appalachian system is more than 1000 miles in length and is approximately 200 miles in width, on an average. Consequently, there seems to be sufficient space for the development of lateral movements within the area due to local causes.

The drowned valleys along the continental coasts show that decided subsidences have taken place. How could these have been caused except by contraction of the columns under the affected areas since the pendulum proves rather conclusively that the regions along the coasts are in isostatic equilibrium? Here the reverse process to that of mountain forming operated.

The writer has arrived at the conclusions here presented after endeavoring to harmonize geodetic data and certain observed geological facts. He makes no attempt to formulate a theory as to what agencies are at work to change the density of material far below sea level (but within, say, 75 miles of the surface), but he suggests that the vertical movements ac-

companying the isostatic adjustments may be a partial cause. Material is moved in this process, to zones of decidedly different temperatures, to hotter or to colder zones, and it seems to be logical to conclude that some chemical or physical changes may take place which would affect the density of the material transported. In the process of isostatic adjustment all the material of a column above the zone of flow is raised or lowered. The ordinary thermal expansion of the material of a column, as it changes its temperature, is capable of accounting for only a small part of the changes in the length of a column.

It should be clearly borne in mind that the theory of isostasy does not explain any vertical movements other than those necessary to maintain equilibrium. Some other theory is needed to explain elevation and subsidence and the writer feels that the theory of local expansion and contraction is in general in harmony with the geodetic data. He believes, however, that there are local vertical movements of small amounts which may not be due to these causes.

It is hoped that increased activity will take place in collecting geodetic data and in extending the investigations in isostasy. It is particularly desirable that we have the investigations include the ocean areas as soon as geodetic data may be available within them.

[1] See page 90, "Investigations of Gravity and Isostasy," *Spec. Pub. No.* **40,** *U. S. Coast and Geodetic Survey*, 1917.

[2] "Strength of the Earth's Crust," by Jos. Barrell, *J. Geol.*, January-February, 1914 (48); and "Discoidal Structure of the Lithosphere" by Bailey Willis, *Bull. Geol. Soc. Amer.*, June 30, 1920.

[3] "Investigations of Gravity and Isostasy," *Spec. Pub.* **40,** *U. S. Coast and Geodetic Survey*, pp. 70–82.

[4] "Investigations of Isostasy in Himalayan and Neighboring Regions," *Professional Paper No.* **17,** by S. G. Burrard, former Surveyor-General of India, 1918.

EXPERIMENTS ON THE ELECTRICAL CONDUCTION OF A HYDROGEN ALLOY

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Communicated by O. Veblen. Read before the Academy, November 17, 1920

In studies which were described some time since[1] it was found that hydrogen, when discharged electrolytically upon any one of certain metals which occlude it, produces a temporary diminution in the electrical resistance of the metal. With metals, such as palladium, which occlude large amounts, and suffer, as has long been known, a lasting *increase* of resistance, the diminution of resistance, or supplementary conductance, is superimposed upon the opposite and more enduring effect; while in the